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Design and Assembly of Acetone Distillation System

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Design and Assembly of Acetone Distillation System

**A Major Qualifying Project submitted to Worcester Polytechnic Institute in partial
fulfillment of the requirement for the Degree of Bachelor of Science**

Submitted on: March 22nd, 2019

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This report represents the work of four Worcester Polytechnic Institute undergraduate students submitted to the faculty as evidence of completion of a degree requirement.

Worcester Polytechnic Institute routinely publishes these reports without editorial or peer review. For more information about the project's programs at Worcester Polytechnic Institute please see <https://www.wpi.edu/project-based-learning>

Abstract

Acetone and other volatile solvents are often utilized in industrial applications. Acetone is mainly used for industrial cleaning when lab material is contaminated with undesired residue. After the acetone is used to clean lab equipment, often times companies discard the solvents at a large expense. This project focuses on creating a small scale acetone distillation system to purify these contaminated solvents in order to reuse them. This paper will outline the research, design, and assembly of this system. The group assembled the contaminated acetone distillation system and provided recommendations for improvements to the system that can create a more efficient and commercialized distillation unit.

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1.0 Introduction

Excessive amounts of acetone are used throughout many industries to clean anything from large scale machinery to laboratory equipment. The excess acetone along with other chemicals and other dirty materials that it collects are discarded by waste companies at a substantial fee along with added negative environmental impacts. When acetone is used to clean machines, the dirty acetone is collected into barrels which are labeled as hazardous waste, and then shipped to off-site locations. These barrels cost thousands of dollars to discard and have to be transferred to a separate location for proper disposal. This causes financial strain on the company as well as environmental strain from the transportation of dirty acetone. To alleviate the cost and environmental impact of disposing acetone, research has been done to make small scale in house distillation machines. These machines would mimic the recycling process done at large disposal companies. Additionally, small scale machines allow small companies to distill their own acetone and avoid both the costs and environmental impacts of large scale disposal. These machines still cost thousands of dollars to purchase, thus they are not widely used and popular as of yet (Tool Discounter, 2019).

Worcester Polytechnic Institute (WPI) has created a research space for individuals to explore an alternative to disposing of acetone more effectively. Past research has established a conceptual basis to create a small scale acetone distillation machine that is affordable and will have a positive environmental impact by reducing waste (Gorilla Bin, 2015). The goal of this project was to further the address the issues of disposing acetone and to develop and design an affordable solution. This project was adapted from the previous work at WPI and will create and improve a small scale acetone distillation machine. Through this project, we have overcome obstacles in designing a system that can potentially be standardized on a large scale. We recommend future implementation of this unit at small companies upon completion of the listed improvements in order to commercialize the product. Upon completion of this system, small companies will be able to alleviate both the financial and environmental strains associated with disposing dirty acetone.

2.0 Background

Acetone is a universally exploited material with many applications ranging from large scale machinery to simply cleaning laboratory instruments. By using a small scale machine to distill acetone, it will reduce cost and help the environment. In this chapter, we discuss the importance of the acetone industry, along with its environmental and financial impacts.

2.1 What is Acetone and What is it Used For?

Acetone (Dimethyl-ketone) is a solvent with both low boiling temperature and pressure, most commonly used in industrial cleaning. Some examples of its uses are the fabrication of fiber optics, electronic circuits, and preparing metal surfaces for painting. Additionally, it can also be used as a degreaser. Acetone is a colorless liquid and is used due to its low-cost, non-toxic properties. It is extremely volatile and flammable and needs to be contained in a controlled, closed environment. Acetone waste is required by the U.S. Occupational Safety and Health Administration (OSHA) to be sent to an approved waste or incinerator facility (Weires et al., 2011).

It was first published in the middle of the 19th Century by a German scientist August Kekule who published the modern structural formulation in 1865 (Kolb, 1978). In 2010, the production of Acetone was estimated to be 6.7 million tons in 2010. At the time the United States was the leading producer with 1.56 million tons ("Chemical Industry Market Intelligence," 2010). Some of the basic properties can be found in the table below.



Figure 1: Acetone in a glass container.

Basic Formula	C_3H_6O
Density (liquid)	0.7845 g/cm ³
Boiling Point	56°C, 133°F
Specific Heat	2.161 kJ/kg*K
Heat of Evaporation	538.91 kJ/kg
Vapor Pressure	30.6 kPa at 25°C

Table 1: Basic Properties of Acetone.

2.2 The Distillation Process of Acetone

The distillation process is currently performed one of two ways. The first being in large scale incinerator facilities and the other is completed in extremely small laboratory experiments. The process is still the same and is as followed.

The waste acetone is transferred into a closed container. Heat is applied by transferring heat stored in hot water in baths or pipes. The acetone evaporates and leaves behind the undesired waste. The acetone vapors then condense back into a liquid by cooling gaseous fluid. (Weires et al., 2011). The unclean acetone is tested for its level of purity. The condensed waste is disposed of properly. Below are images of the two processes, the large scale incinerator facility and the small scale laboratory experiment.

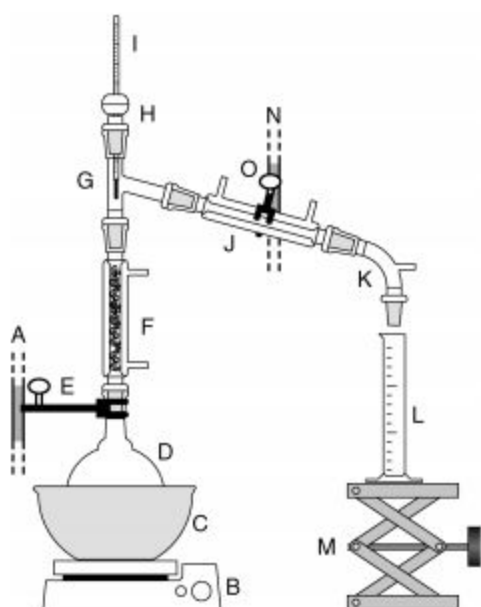


Image 2: Lab Distillation.

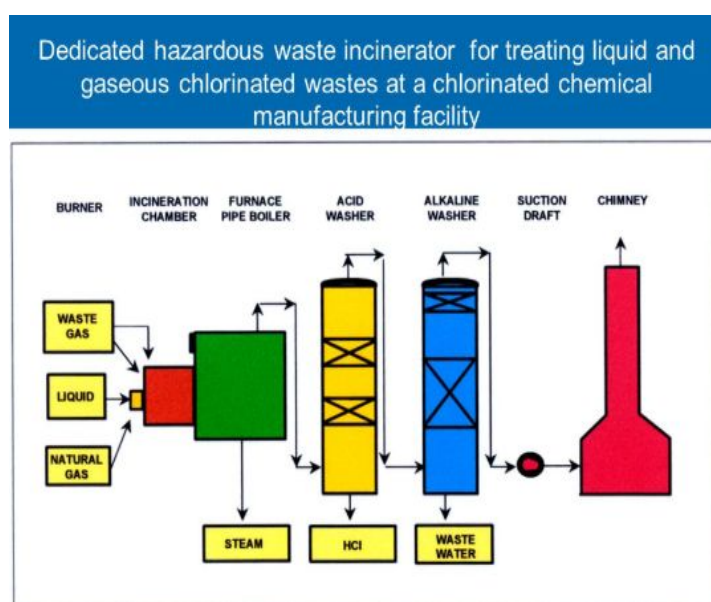


Image 3: Incinerator Facility Distillation.

2.3 Environmental Effects

The waste industry often goes unseen yet it has lasting negative effects on the environment. When acetone is used to clean industrial facilities, the dirty acetone is collected in barrels. These barrels are picked up and transported to recycling facilities where a large scale distillation occurs. In order to responsibly dispose of the acetone, it needs to be transported which causes air pollution. Additionally, the large amounts of energy and fuel necessary to run a large scale distillation facility also negatively affect the environment.

There are also consequences when acetone is not disposed of properly. One example of discarding chemical waste improperly is the process of dumping it, causing the chemicals to leach into the soil, contaminating it (Gorilla Bin, 2015). Chemicals can also run-off into nearby water sources, affecting the ecosystem and life, as well as contaminating potential drinking water. Pollution is also associated with both transportation and open-air dumping of hazardous

chemicals. These harmful chemicals can evaporate into the air and sometimes other disposal methods, including incinerators, are used to burn off the hazardous chemicals (Gorilla Bin, 2015). While there are a significant number of other causes of pollution from improper chemical disposal, recycling acetone on a smaller scale can help to eliminate a greater portion of these negative environmental impacts.

3.0 Methodology

The goal of this project is to create an in-house machine that will recycle dirty acetone to be reused again. Our team formed the following objectives to achieve this goal:

1. To design a system that is effective and efficient
2. Instill sensors/controls to make the system user friendly.
3. To construct a machine that can be implemented in manufacturing facilities.

In the following sections, we describe the process we used to achieve these objectives. We explain how research, testing, and guidance were used to create a final product.

As previously stated, the goal of this project is to create an in-house machine that will recycle dirty acetone to be reused again. In previous years, other Major Qualifying Projects have attempted to accomplish this task by taking a chemical engineering-oriented approach which unfortunately, was not successful. However, our group decided to undertake this task from a mechanical engineering perspective by exploiting specific properties of acetone, particularly, its extremely low boiling point. Similar to large-scale acetone recycling, the basic concept of boiling off acetone from other materials persists as the fundamental element of the distillation process. By designing a small-scale, safe, and mobile distillation apparatus, we can successfully mimic expensive and large-scale recycling processes and allow this method to be utilized on a greater scale allowing more companies the opportunity to purchase a system that was previously unaffordable.

3.1 Objective 1: To Design A System that is Effective and Efficient

The acetone recycling system itself stands at a total of six feet, four inches tall. It is comprised of three levels that are each roughly 38 inches by 30 inches supported by four 72 inch tall vertical beams resting on four wheels to provide mobility. The bottom level of the system contains the contaminated acetone storage tank and a singular pump that connects it to the heat source tank. In this chamber, the dirty acetone is stored before it is prepared for the distillation process. Located within the tank is a copper helical tube where hot water from the heat source tank is pumped through so that the dirty acetone can be boiled off through both conduction and convection without ever coming into actual contact with the water. Additionally, protruding out of the tank is a one inch diameter copper pipe that allows the gaseous acetone to travel directly to the third level where the condenser box is located.

The second level of the system is comprised of the condenser pump, the heat source tank, the clean acetone storage tank, the system's electrical components, and an entryway where the user can pour the contaminated acetone into the chamber depicted on the first level. The pump that is fastened to the roof of the second level is responsible for pumping cool water on the third level between the air-cooled heat exchanger and the condenser box. The heat source tank contains an inductive electrical heating coil that allows the water inside the tank to be heated to a temperature that can boil acetone when pumped to the contaminated acetone storage tank. The electrical components include the single element thermostat, both switches that are connected to the pumps, an adapter to reduce the voltages feeding to the pumps, and

the wiring that connects the system's circuit to a wall outlet. After the acetone goes through the distillation process it is deposited into the clean acetone storage container. This process entails evaporating from the contaminated storage tank, flowing through the condensers' copper pipes, and then condensing back into liquid form and falling into the clean storage container. Finally, directly above the contaminated acetone storage tank on the second level is a hole to allow the operator to deposit the contaminated acetone with ease.

The third level is comprised of the air-cooled heat exchanger, the condenser box, the copper piping within the condenser box and a hose that connects the condenser pipes to the clean acetone storage tank located on the second level. Water is pumped from the condenser box to the air cooled heat exchanger and flows back into the box. This feature allows the operator to avoid refilling the condenser box with cool water. The condenser box itself is filled with circulating cool water and contains the copper piping that transports the acetone as it condenses and has separate sealed ports for both the cool water systems and acetone systems to flow individually. Finally, the end of the condenser box is fixed with a steel hose that directs the newly condensed acetone from the third level in the condenser box onto the second level inside the clean acetone storage tank.

Ultimately, the acetone recycling system is composed of two equally important subsystems; the mechanical and electrical. The mechanical subsystem provides the unit with structural support and mobility, as well as different compartments and components for the stages of acetone distillation. The mechanical subsystem was also designed to include the optimal space between the heating and cooling elements that boil and condense the acetone. The electrical subsystem contains the pumps and heaters to effectively process and extract acetone. A more detailed description of both the mechanical and electrical components can be found in Appendix B.

3.2 Objective 2: Instill Sensors/Controls to Make the System User-Friendly

To ease the operation of the system, implementing sensors and controls is recommended to monitor the machines process. Through research and the guidance of an Electrical and Computer Engineer, we were able to create a simple operating system with sensors. The sensors and the simple use of the machine are as followed.

The system itself is divided into two isolated systems. The first one is the hot water system, which delivers hot water to the heating element in the contaminated acetone tank, heating and evaporating the acetone. The other closed system is the cold water system. The cycling cold water causes the evaporated acetone to condense back to liquid acetone.

The system turns on by inserting the plug into any wall outlet. This begins to heat the hot water with a conventional electrical heating coil. This heater is controlled by a thermostat at 60°C (Home Depot, 2019). The temperature can be controlled on the thermostat itself. There are thermometers on each tank that record the temperature of the liquid inside of the tank. These sensors will determine if the thermostat needs to be manually adjusted. Once the hot water has reached the appropriate temperatures, both the hot water and cold water pump can be turned on, circulating the water. The hot water will heat the acetone to a point where it evaporates and flows through the copper piping, where the cold water system starts to

condense it. The acetone travels through a set of copper piping that is inside cool temperature water. Once the liquid acetone has been collected in the clean acetone tank, the system can be turned off. Both pumps should be turned off and the machine should be unplugged from the wall. Once this is done, the system will be off and will begin to cool down. A more detailed description of the instructions can be found in Appendix C.

3.3 Objective 3: To construct a machine that can be implemented in manufacturing facilities

We have now created a prototype of a machine that is simple to use and can be implemented in manufacturing facilities. This machine has the capacity to recycle 18 gallons of contaminated acetone at a time. It is easily maneuverable and simple to operate. The machine is well labeled and has clear instructions to operate. The assembly of the machine took more time than expected and the electrical aspect in wiring the switches, sensors and pumps was challenging. Now assembled, the system successfully evaporates and condenses contaminated acetone under manual supervision of the heating coil.

3.4 Summary

In this chapter, we discussed the method that is used to accomplish the projects objectives. We designed an effective and efficient system by using sensors and controls to ensure the machine is easy to use. We used Solidworks to create an initial design as well as a recommended commercial design, and assembled a machine based on that design that can be implemented in manufacturing facilities. This machine can recycle contaminated acetone allowing for reuse.

4.0 Recommendations

We describe and explain our recommendations in this chapter. We developed the following recommendations to improve the design, production, and use of our machine to enhance the overall ease of recycling acetone on a small scale. This is intended for use by small scale manufacturers or those who will continue to develop this project commercially. We developed recommendations based on literature review and our own finding throughout the course of this project. These recommendations are to serve as a guide for future development of this project. The overall intent of our recommendations is to aid in the ease of recycling acetone.

In order to create a system that is easy to operate, the team recommends adding LED indicators so that the operator of the system knows when the cold water pump needs to be turned on/off and when the heat can shut off. This will also allow the system to operate much more efficiently. In addition to adding indicators, the group also recommends adding level sensors to notify the operator when the hydraulic tanks are full. Taking these measures will allow the operator of the system to understand where the acetone is in the distillation process and guide them in operating the machine.

Our next recommendation is to add aluminum sheeting on all sides of the outer frame of the system and to additionally replace the plywood shelving with aluminum/metal sheeting as well. This will improve the quality of the system and the structural integrity of the shelving. In addition to replacing the shelving with metal sheeting, we suggest using rubber mats to prevent flow of electric current and to reduce sliding of components on the shelves. This will make the system safer to use and easier to move.

It is necessary for the system to have an attachment with a tray for both the removal of leftover acetone sludge and for clean acetone removal. This would be necessary as there will be buildup of debris in the hydraulic tank where the dirty acetone is located. The tray for clean acetone removal is necessary for ease of removal and reuse of the acetone, which is the purpose of the distillation system.

The team also suggests implementing a sturdier condenser box that is secured to the system or bolted down. It may even be necessary to choose a condenser box with a different material, depending on where the environment of the system is located making it much safer. This will make the system more feasible to use in a fast-paced manufacturing environment.

The group suggests using electrical engineers in a future variations of the project. This will allow for a more organized electrical wiring of the system where all of the switches and thermometers can be located in one central panel. An electrical engineer in the project group would potentially have a better understanding of how the wiring and circuitry can be implemented to improve the system and ease the operation of the system. Finally, the combination of electrical and mechanical engineers working on the system design could organize the system most efficiently.

5.0 Conclusion

The goal of this project was to address the cost-related and environmental issues that disposing acetone has on companies, and create an in-house machine that will recycle dirty acetone to be reused again. Acetone and other volatile chemicals used for cleaning become contaminated after they are used, and create substantial expenses for disposal.

The group has designed, developed, and implemented a possible solution for reusing acetone and other volatile chemicals instead of disposing them and suggested recommendations for future iterations of the system that would improve upon the efficiency of the system such that it can be used in a manufacturing facility. The group was able to come to the final result after beginning with a process of intensive background research to understand the properties of acetone, the distillation process itself, and the environmental impacts. The group learned that there were many precautions required when using a system with acetone of its high level of flammability. Because this was a continuation of a past MQP, the group studied the previous report and reverse engineered the design to create a design that we found to be more effective. After deciding on a design, the team created a potential model in Solidworks and then implemented the design. After completing the construction of the system, changes were made to make the final product the most effective and usable.

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Appendices

Appendix A: CAD Design of Machine

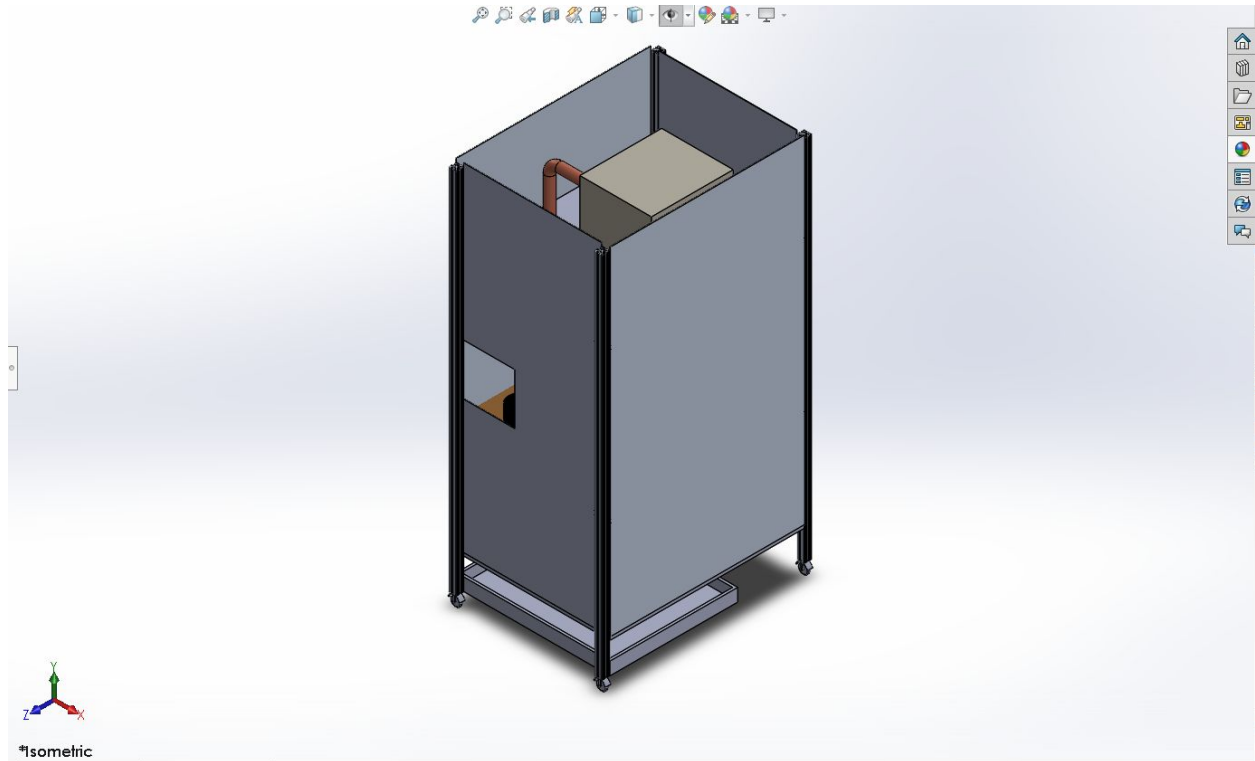


Image 4: Isometric View of SolidWorks Model- Including Aluminum Front, Back, and Side Panels

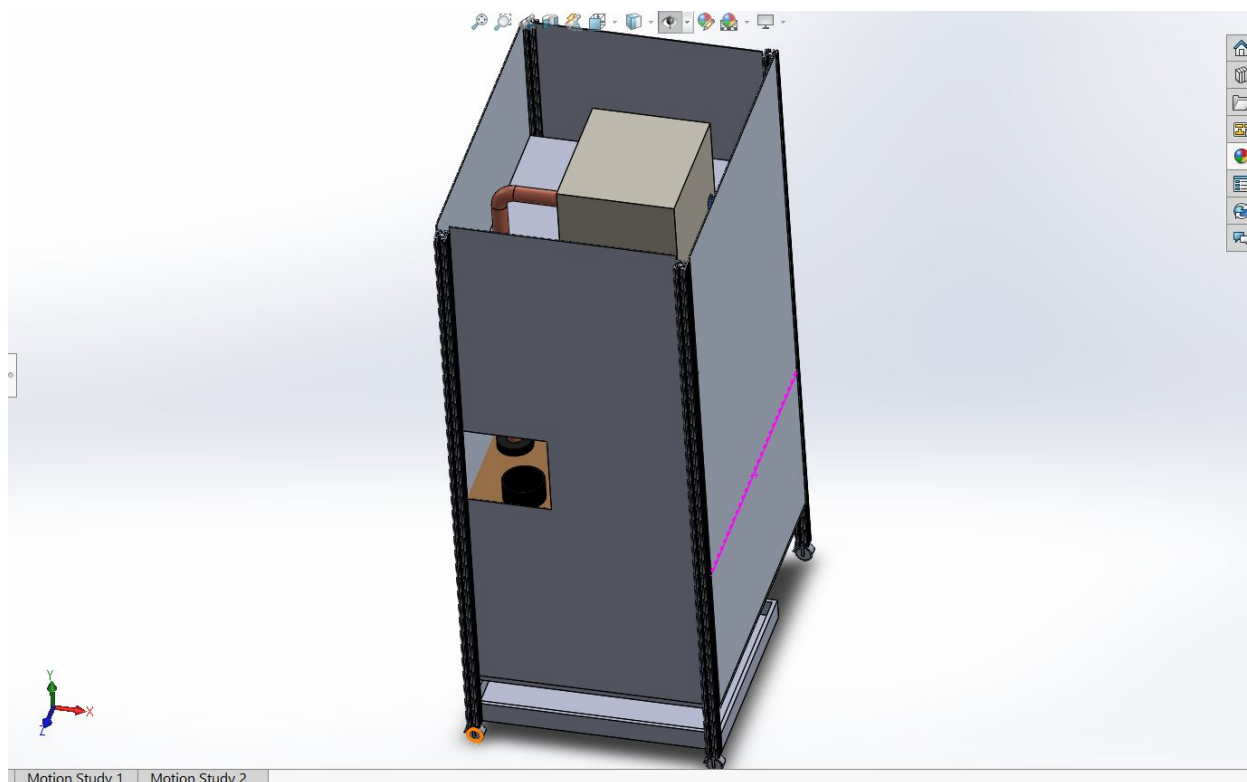


Image 5: Adjusted Isometric View of SolidWorks Model- Showing Fill-Up Location for Dirty Acetone

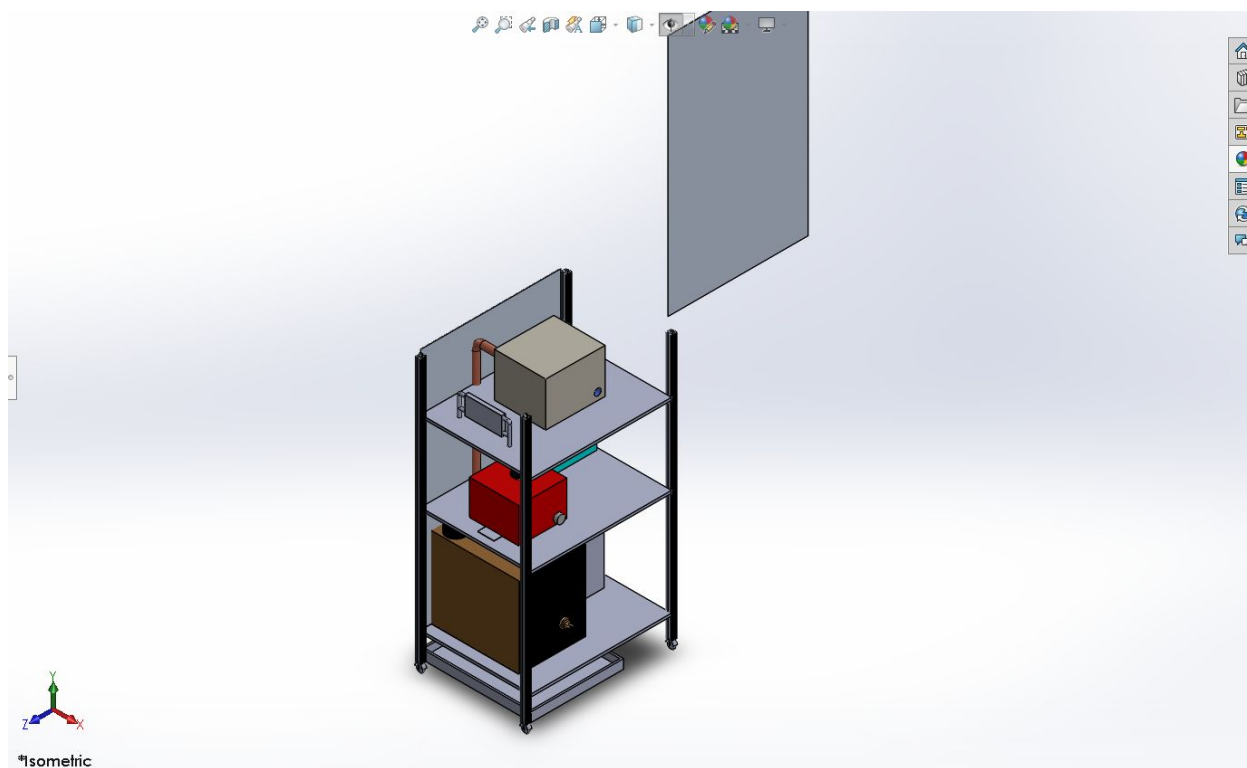


Image 6: Isometric View of SolidWorks Model Without Aluminum Front and Side Panels

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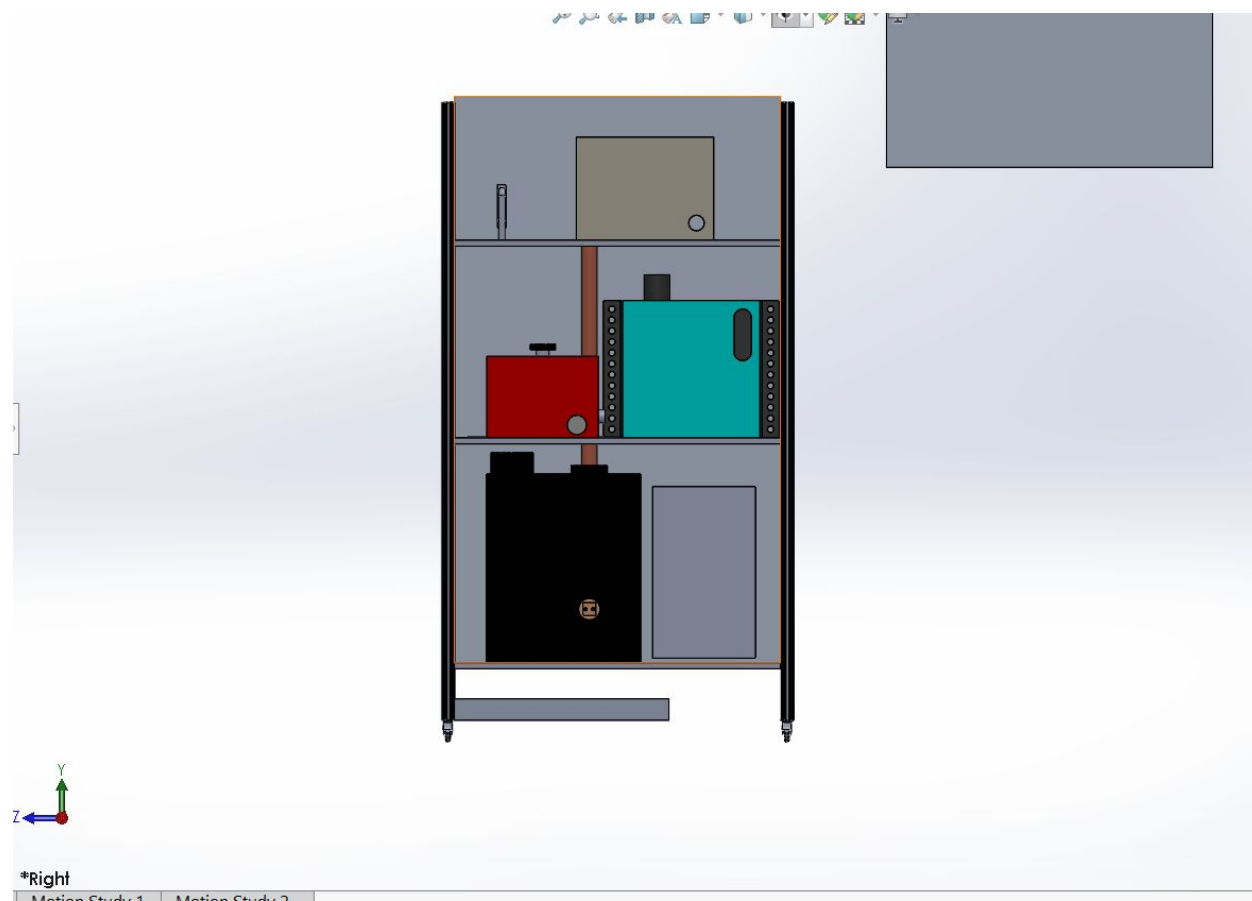


Image 7: Right Side View of SolidWorks Model Without Front Aluminum Panel

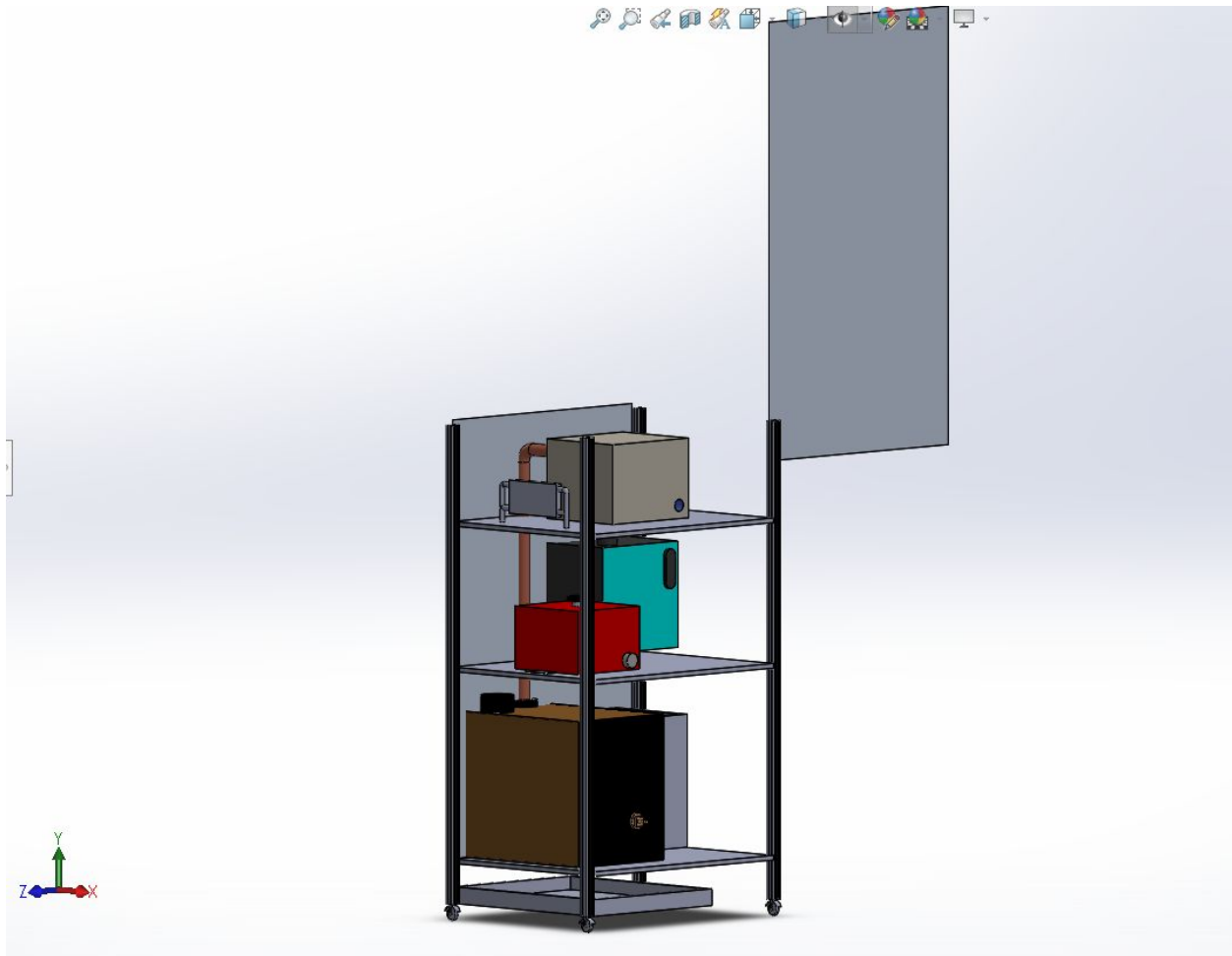


Image 8: Adjusted Isometric View of SolidWorks Model Without Front Aluminum Panel For Enhanced View of Components

Appendix B: Description of Electrical and Mechanical Components

List of Mechanical Components:
25mm x 25mm T-Slotted Profile- Four Open T-Slots Vertical Support Beams (4)
38 inch x 30 inch Slotted Horizontal Support Beams (3 sets of 4)
.75 in. thick 38in. X 30in. Plywood (3)
Wheels (4)
Diagonal Steel Supports (4)
Bayite BYT-7A006 DC 12V Solar Hot Water Heater Circulation Pump (2)
500mm Stainless Steel 2 Ball Water Sensor Vertical Float Switch (1)
300mm Stainless Steel 2 Ball Water Sensor Vertical Float Switch (1)
Screw In Element- 2000W 120V HWD Bilingual (1)
Copper Pipe Insulation(1)
1 inch diameter Copper Pipe (1)
5 Gallon Nortrac Steel Hydraulic Fluid Reservoir and Thermostat (Heat Source Tank) (1)
25 Gallon Buyers Hydraulic Reservoir- Model #SMR255 (Contaminated Acetone Compartment) and Thermostat (1)
15 Gallon Buyers Hydraulic Tank- Model #SMR15S (Acetone Storage Compartment) and Thermostat (1)
Plastic Condenser Box Storage Container (1)
Fluid Cooling Mobile DH Series (1)
PVC Clear Tubing
Helical Heating Element Coiled Copper .375 in. Diameter and 20 in. long (1)
.5 in. Diameter Copper tubing in Condenser Box (1)
General Purpose Worm-Drive Clamps for Firm Hose and Tube (12)
Plastic Pipe Fittings on Condenser Box (2)
Thick-Wall Brass Threaded Pipe Fitting for Acetone(1)
Fire Extinguisher (1)
Zip Ties (5)

Description and Function of Mechanical Components

25mm x 25mm T-Slotted Profile, Four Open T-Slots

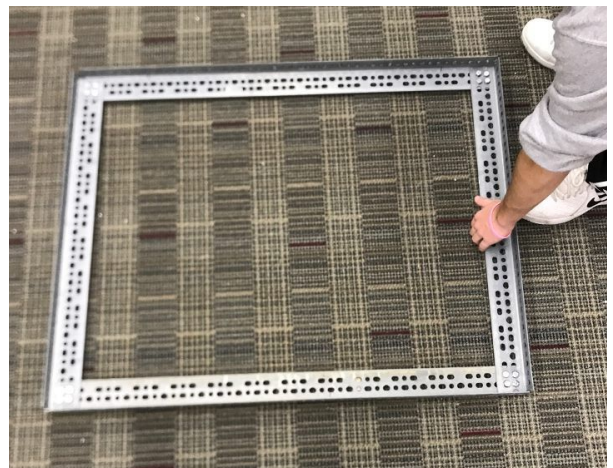
Vertical Support beams:

In our initial design, we had originally elected to create a system that was mobile both internally and externally. Not only was it imperative that our system be safely transported, but we had also designed each “level” within the system to be capable of moving vertically. In order to assure that this mobility was possible, we secured each layer to all four support beams using L-brackets which could easily be slid up and down simply by loosening the bolts located in each corner. With this design, the total height of the system could be elongated or shortened by the user with little effort (80/20 Inc., n.d.).



38 Inch x 30 inch Slotted Horizontal Support Beams:

The purpose of using slotted horizontal support beam was to provide the skeletal structure of the system. Each individual shelf is composed of (2) 38 inch slotted support brackets bolted to (2) 30 inch slotted support brackets which compose the rectangular framework for each of the 3 levels. The steel beams were used because of its durability. Additionally, because the support brackets were fastened to the T-slotted vertical support beams, the level and height of each shelf could be quickly adjusted to fit the needs of the user.



.75 inch Thick Plywood:

We chose to manufacture the system with each level resting on top of the .75 inch thick plywood because this is a prototype. Plywood is a cheap, sturdy material that will uphold the structural requirements of the system. The benefits of using this material was that we could quickly and adjust the plywood to the desired orientation. As opposed to materials such as aluminum or steel which would be used in a final product replication of the acetone recycling system, we could easily drill holes for tubing and electrical wires that ran between different levels of the system. Additionally using plywood allowed us to secure each level and the systems' structural integrity.

Wheels:

As previously stated, one of the main goals of the system was that it must be capable of being transported between locations. Thus mobility was an important factor that we needed to incorporate into our design. The placement of four wheels that were fastened into the vertical support beams successfully allowed us the ability to transport the system without any risk of failure.

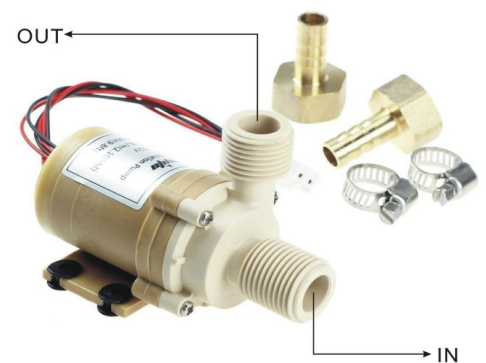


Diagonal Steel Supports:

In order to add more structural support to the system, we added diagonal steel supports. These supports reduce stress on the vertical beams.

Bayite BYT-7A00 DC 12V Solar Hot Water Heater Circulation Pump:

As previously discussed, the acetone recycling system can be comprised of three separate subsystems. The first isolated system is related to the acetone entering the contaminated acetone compartment which boils in the chamber where it follows a series of copper pipes that condenses the acetone into the storage compartment. This would be referred to as a passive subsystem because here, the properties of acetone alone allow it to move from beginning to the end of the recycling system. However, the other two systems allow the water to be circulated in order to heat and cool the acetone and require two active pumps to circulate the water. One of these pumps connect the contaminated acetone compartment to the heat source tank. Here water is pumped from the heat source tank through the contaminated acetone compartment and back up to the heat source. The other pump is used to circulate the cool water from the condenser box through the heat exchanger and back to the condenser box and is responsible for the condensing the gaseous acetone at the top of the system (Bayite, n.d.).



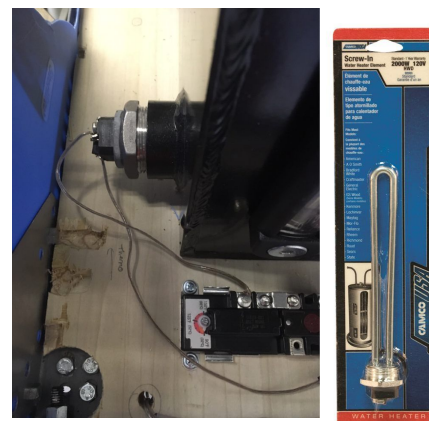
500mm Stainless Steel 2 Ball Water Sensor Vertical Float Switch / 300mm Stainless Steel 2 Ball Water Sensor Vertical Float Switch:

In the system, the longer 500mm stainless steel 2 ball water sensor is placed in the contaminated acetone storage tank while the shorter 300mm stainless steel 2 ball water sensor is placed in the smaller 15 gallon clean acetone storage tank. The purpose of these sensors is to allow the user to know when both tanks are filled to maximum capacity and when they are empty (DealMux, n.d.).



Screw In Element-2000W 120V HWD Bilingual

The screw in element is located on the 5 gallon Nortrac Steel Hydraulic fluid reservoir which we refer to as the heat source tank. The screw in element utilizes inductive heating where a strong current is passed through the coils which causing the surrounding water in the tank to heat by conduction and convection. After the water reaches a certain temperature, (60- degrees Celsius) it is pumped into the contaminated acetone compartment where the heat from the water leaving the heating element is transferred into the contaminated acetone on the first level heating the acetone in the storage tank (CAMCO, n.d.).



Copper Pipe Insulation:

The insulation is located around the 1 inch diameter vertical copper pipe ensures that heat does not escape the system and fall back into the contaminated storage tank (McMaster-Carr, n.d.-a).



1 inch Diameter Copper Pipe:

The 1 inch diameter copper pipe connects the contaminated acetone storage tank on the bottom level to the condenser box to the top level of the system. In order to avoid acetone leaking in its gaseous state, the bottom end of the pipe is threaded and welded to the contaminated acetone storage compartment. At the top of the pipe we soldered several other copper pipe connectors that directs the evaporated acetone through the condenser system. Here, we minimized the length of this pipe to assure that the acetone does not lose too much heat as it travels up the system's levels to the point where it condenses and falls back into the contaminated acetone chamber. Copper is selected as the material for this piping because it is relatively cheap material with superb qualities of conducting heat compared to other materials.

5 Gallon Nortrac Steel Hydraulic Fluid Reservoir and Thermostat (Heat Source Tank):

As previously stated, it is important that we keep each subsystem that utilizes the heating and cooling of water completely separate from the components that store acetone. The heat source tank is connected to the contaminated acetone storage tank where hot water is pumped between both chambers. Inside the heat source tank is the induction heating element which can be adjusted to any desired temperature using the single electrical heater. The heat source tank is located on the second level of the system just next to the copper pipe leading out of the contaminated acetone storage compartment and weighs roughly 21 pounds. The reasoning for this placement is due to the intensity of the heat from the induction coil, heat



will escape from the heat source tank no matter what. Thus, if the heat source tank is located next to something in the system which requires heat, then the optimal placement in the system would be next to the copper pipe. The heat source tank is made out of welded 12 gallon powder coat steel and is roughly 13 3/10 inches long by 13 3/10 inches wide and 9 7/32 inches tall (Northern Tool, n.d.).

25 Gallon Buyers Hydraulic Reservoir- Model #SMR255 (Contaminated Acetone Compartment) and Thermostat:

The Contaminated Acetone Compartment is listed as a 25 Gallon hydraulic reservoir weighing roughly 73 pounds when empty. However, the maximum storage capacity of the tank is actually only 18 gallons which means that the user filling it should really only have to fill it halfway to about 9 or 10 gallons. The contaminated acetone storage tank is made of 13 gallon steel and is 20 1/16 in. by 18 3/8 in. by 15 in. Inside this tank is a divider wall which stops the contaminated liquid from coming into contact with the hot water. A helical copper heating element is inserted inside the tank which provides an area for the water to be circulated through the tank without ever actually coming into contact with acetone itself. The water is pumped from the heat source tank, into the helical heating element which passes through the bottom of the contaminated acetone compartment and eventually flows back up into the heat source tank. Located at the bottom of the tank is a twistable cap which can be removed and is used to empty the rest of the waste after the acetone is boiled off.



15 Gallon Buyers Hydraulic Tank- Model #SMR15S (Clean Acetone Storage Compartment) and Thermostat:

The 15 Gallon Clean Acetone Storage Compartment is located on the second level of the system and weighs about 57 pounds. The tank itself is made out of 13 gallon steel and is 13 1/2 in. by 15 1/2 in. by 17 1/2 in. Additionally, the shape of the tank is the identical to the 25 gallon tank only smaller in size. After the acetone is finally condensed on the top level in the condenser box, a hose feeds the liquid acetone from the top level down into the second level. After the tank is filled or the user decides that the tank is filled enough, a plug can be unscrewed on the bottom of the tank where the acetone can be extracted for further use. Finally, the flanges located on the rear side of the tank are fastened to the horizontal support beams to make sure the system does not collapse due to its own weight.

Plastic Condenser Box Storage Container:

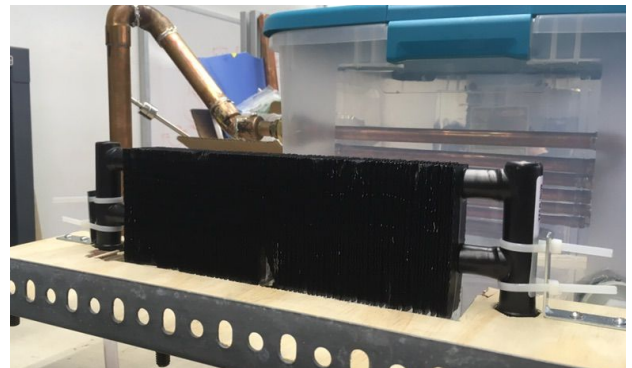
The condenser box is located on the top level of the system which the user can fill with 16 gallons of cold or room temperature water. Running through the condenser box is a .5 inch diameter copper tube sloped at a downward angle so that the acetone can be afforded enough

time to condense from vapor to liquid form. Due to gravity, the newly condensed liquid acetone will follow the copper piping which leads into the clean acetone storage compartment. The condenser box itself is equipped with 4 holes that provide entry and exit for both water and acetone in two isolated systems. On the rear side of the condenser box, holes on the top left and bottom right of the box provide the route that acetone will follow as it condenses to liquid form. On the bottom and front left side of the condenser box are holes that allow cold water to be circulated throughout the system. Here cold water leaves the condenser box to a pump located on the second level of the system. This pump then pushes the water through a air-water heat exchanger that resembles an automobile radiator where airflow dissipates the heat which is provided by a set of small fans. After the water leaves the heat exchanger and the heat has been extracted from it, the water is then pumped back into the condenser box.



Fluid Cooling Mobile DH Series:

The fluid cooling mobile DH series acts as a heat exchanger and dissipates heat gained from the water in the condenser box collected through conduction of the copper pipe carrying warm acetone by delivering it to the surrounding environment. The heat exchanger is similar to an automobile radiator and connects both the entry and exit points for water in the condenser box. The heat exchanger dissipates the heat from the water traveling through it by utilizing a series of fins that help to extract the heat. The numerous fins of the heat exchanger allow the device to maximize its surface area and extract the heat from the water passing through it. A small fan aids in the effort in dissipating the heat from the water to the surrounding environment. Additionally, the heat exchanger is mounted slightly above the top level of the system so that the PVC tubing attached to it could avoid kinks that would restrict the flow of water and the inherent stresses on the pump. Finally, the heat exchanger is mounted by fastening two small L-brackets with zip ties attached to it to be sure that it stays in place both while the system is running as well as while the system is transported.



PVC Clear Tubing:

For both isolated systems that are responsible for pumping water in their respective subsystems, we elected to use PVC tubing. Due to the corrosive properties of acetone that

would deteriorate this material, we could not use the PVC tubing in any system that came into direct contact with the acetone. However, PVC tubing proved to be the best option for systems pumping both hot and cold water because not only could it easily tolerate temperatures between -40F and 175F, but the material is also very sturdy and could easily be fastened to different components such as the pumps and the different compartments in the system. Ultimately, this tubing served the purpose of transporting and circulating water throughout different locations in the system (Small Parts, n.d.).



Helical Heating Element Coiled Copper .375 inches Diameter and 20 inches long:

The helical heating element coiled copper tube is located inside of the 25 gallon contaminated acetone storage tank. As previously stated, when designing the system, it is imperative that both the electrical components and water remain completely separate from direct contact with acetone. As a result, by pumping hot water generated by heat source tank through the PVC tubing and into this copper tubing, we can utilize both conduction and convection in the contaminated compartment in our effort to boil off the acetone mixed in with the other unwanted waste. It is important to note that this copper heating element is hollow so that the water can flow through it and provides both the inlet and outlet locations for the water entering and exiting the contaminated acetone storage tank



(“Design_and_Construction_of_an_Advanced_Solvent_Recycling_System_MQP_Report.pdf,” n.d.).

.5 inch Diameter Copper tubing in Condenser Box:

As previously stated, the condenser box serves the purpose of condensing the acetone in vapor form back into liquid form so that it can be extracted and reused.

Additionally, we decided to utilize copper piping for this process because of the material's superb qualities of conducting heat and the convenience of fabricating and soldering copper pipes. By including several turns of the copper pipe, we were capable of maximizing the surface area of the pipes leading to the greatest amount of heat dissipation from the warm vapor into the the cool water of the condenser box. This process allows the acetone to revert back into liquid form for extraction as it reaches the end of the condenser box. Additionally, the copper



pipng is sloped at a downward angle so that gravity could act on the liquid acetone and direct it to the clean acetone storage tank.

General Purpose Worm-Drive Clamps for Firm Hose and Tube:

The worm-drive clamps served the purpose of assuring that, as water passes through the PVC tubing to the pumps or different compartments, we could avoid the tubing's tendency to slide off of each component. Due to our compact design, the first and second level of the system houses all of the electrical components. If these electronics come into contact with acetone or water they may short-circuit, causing the system to fail and potentially be dangerous for the user to touch. By securing each pump and compartment with these clamps we can be sure to avoid leakage and evade this potential hazard (McMaster-Carr, n.d.-b).



Plastic Pipe Fittings on the Condenser Box:

The plastic pipe fittings are located on the front left side and bottom of the condenser box. As we are cycling water in and out of the condenser box, we needed to be sure that these ports are water-tight to avoid leakage out of the condenser box into the rest of the system. These pipe fittings connect the PVC tubing to the water flowing in and out of the condenser box and assure that we can avoid leakage as the system is running (McMaster-Carr, n.d.-c).



Thick-Wall Brass Threaded Pipe Fitting for Acetone:

Similar to the plastic pipe fittings associated with circulating water in the condenser box, the threaded brass pipe was is used to transport the gaseous acetone from the 1 inch diameter copper pipe to the .5 inch diameter copper piping inside the condenser box. However, unlike the plastic pipe fitting which is equipped to transfer water, we elected to use a brass pipe fitting so that it could withstand the corrosive properties of acetone while still being both water and air-tight around the condenser box (McMaster-Carr, n.d.-d).



Fire Extinguisher:

As previously stated, acetone is a highly flammable substance that has been known to ignite even when all the necessary precautions have been taken. Any spark or obsessive heating within the system could potentially cause the acetone to combust and we must be sure to have taken every precautionary measure to ensure that not only the system, but the people around it are safe. As a result we have provided a fire extinguisher with the final assembly.

Zip Ties:

Within the system there are 5 zip ties. 4 zip ties are used to secure the heat exchanger on the top level of the system to assure that it is grounded and not at risk of tipping. Additionally, one zip tie is used to help support the .5 inch copper piping in the condenser box. Here the zip tie is not fully tightened for the reason that the copper tubing must be fixed at a downward slope to allow gravity to pull down the condensed liquid acetone and lead it to the clean acetone storage tank.

List of Electrical Components:
T-O-D H/HLC Single-Element Thermostat for Residential Water Heaters (1)
LE Power Adapter, 2A, AC 100-24 V to DC 12V Transformer, 24W Switching Power Supply
Wall Switches (2)
Junction Boxes (4)
Wall Outlet (1)
Electrical Caps (6)
18 Gage Wire (1)
Wall Wire (1)
Wall Plug (1)

Description and Function of Electrical Components

Therm-O-Disk H/HLC Single Element Thermostat for Residential Water Heaters:

In the acetone recycling system, the single element thermostat is connected to the screw-in inductive heating element located inside of the heat source tank on the second level. The single element thermostat is attached to a power source that draws electricity to generate heat in the heat source tank which is transferred to the water through conduction and convection. This thermostat is equipped with a reset button affixed to the top of device which restarts the component if it begins to overheat. Additionally, on the bottom of the device is a dial that can be manually turned which directly affects the amount of power drawn to the inductive

heating coil. The amount of power drawn to the heating coil is directly related to how hot the coil is inside the tank. The temperature range of the device varies between full power at 66 degrees Celsius (150 degrees Fahrenheit) and 32 degrees Celsius (90 degrees Fahrenheit). As previously stated, acetone evaporates at 60 degrees Celsius therefore, before the user begins



to circulate the hot water between the heat source tank and the contaminated acetone storage tank, the user must be sure that dial is properly fixed and the thermometer on the outside of the heat source tank has reached 60 degrees Celsius. Additionally, because this is a single element thermostat, it differs from more common residential two-piece water heater thermostats because it runs under continuous operation. This means that when the user begins to operate the system, he or she adjusts the dial to their preferred temperature. The device will continue to draw electricity and heat the induction coil until it satisfies the preset conditions which is set by the user on the dial. Once this point is reached, the device will cease drawing power from the system until the temperature drops below the preset parameters. Because the singular thermostat undergoes continuous operation, it does not permanently cease drawing power. Rather it will reactivate itself again to ensure that the electricity drawn satisfies the preset temperature which the user placed on the dial in the first place. As depicted to the right, you can see the single element thermostat in our system with its respective electrical diagram.

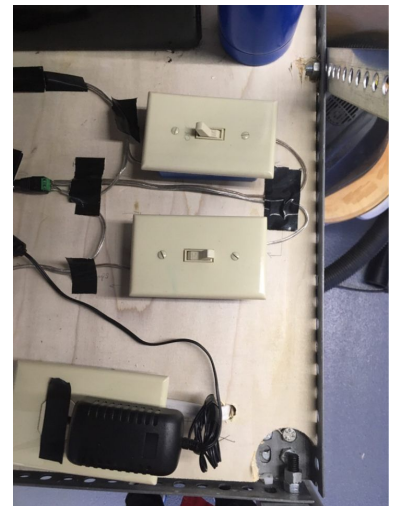
LE Power Adapter, 2A, AC 100-24 V to DC 12V Transformer, 24W
Switching Power Supply:

Within the system, the purpose of this adapter is to convert the voltage from the wall outlet from AC to DC and reduce the voltage from 120 Volts to 12 Volts. Here, this adapter is connected to the switches that allow both pumps to operate efficiently at their respective voltages (Lighting EVER, n.d.).



Wall Switch:

The system is supplied with two individual wall switches that are connected to both pumps in the heating and cooling phases of the system. Due to the fact that it takes time for water to be heated such that it will effectively boil the acetone, each step for operating the heating element and each pump must be separate from one another. Only when the water in the heat source tank reaches the desired temperature should the user begin to pump this water to the contaminated acetone storage tank to begin evaporating the acetone from the rest of the contaminants. When this temperature is reached, the user may flip the wall switch which will initiate the pump and commence circulating hot water used to boil acetone. Additionally, the other wall switch is connected to the pump which is responsible for circulating cold water between the heat exchanger and the condenser box on another separate system.



Junction Boxes:

The purpose of the junction boxes is to isolate any electrical components from the rest of the system to avoid leaking water getting into them as well as isolating live electrical components.

Wall outlet:

The system also required a wall outlet for the power adapter to feed into both of the pumps. The power supplied to the entire system itself is taken from a typical wall outlet found in almost every building. In order to change the voltage and current to a level that allows the pumps to function, we needed to add in a wall outlet within the system which the power adapter could be plugged into to provide tolerable voltages to other electrical components.

Electrical Caps:

The electrical caps are responsible for confining the unprotected electrical wires and keeping them away from the rest of the system. The wires that are visible in the system are all covered with the rubber insulation as well as electrical tape to ensure water cannot short-circuit them. However, on the ends of the circuit where we connected electrical components, we had to strip the wires exposing the live metal ends. The electrical caps assure that these wires are safe for both the system and the user.

18 Gage Wire:

This wire is responsible for connecting the several electronics located in the system. Power is drawn from a nearby wall plug and dispersed to the rest of the circuit including both pumps, the heating element, the adapter, and several switches. The 18 gage wire serves the purpose of connecting these components.

Wall Wire:

The wall wire connects the wall plug to the gage wire which supplies power to the rest of the systems electronic components.

Wall Plug:

As part of our design to create a mobile acetone recycling system, it is imperative that our system can be used in a variety of different environments. By designing our electrical circuit using the standard wall-plug found in virtually every building, we can be sure that our system can be run almost anywhere given the proper safety precautions are taken. The wall plug provides the power by connecting the wall outlet of any building to the rest of the electronic components within the recycling system.

Appendix C: Detailed Description of Operation

1. Pour contaminated acetone into the appropriate tank to about half way. This is approximately 12 gallons. This tank is labeled.
2. Plug machine in to a wall outlet.
 - This will begin to run power to the thermostat and the electrical heating element.
3. Ensure that thermostat is dialed to 65°C.
 - This is the boiling point for acetone.
4. When the thermometer outside the hot water tank reads 65°C turn on both the hot water and cold water pumps from off to on. These look wall light switches. They are labeled.
 - This will begin to pump the hot water into the copper coil inside the contaminated acetone tank. This will heat up the contaminated acetone to boil and evaporate.
 - The evaporated acetone will travel up the copper pipe up to the third level. It would continue to travel through the copper piping.
 - The evaporated acetone travels through a zig zag of copper piping that is emerged in a box of room temperature water. The room temperature water will remove the heat from the acetone and the evaporated acetone will condense into a liquid form.
 - The cold water pump will also be circulating the cold water.
 - The water that removes the heat from the acetone will travel through the heat exchanger. This will remove the heat from the water and the water will recirculate into the condenser box and will continue to remove the heat from the evaporated acetone.
 - The now clean liquid acetone will flow into the clean acetone tank.
5. Once all the acetone has flowed into the clean acetone tank the system can be turned off to cool off
6. The hot water and cold water pump can be switched from on to off.
7. Unplug the machine from the wall outlet.
8. Allow the system to cool off.
9. Remove the clean acetone from the tank.